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(54) **PIEZOELECTRIC ACTUATOR OF INK JET PRINTER HEAD**

(75) Inventors: **Jun Isono**, Nagoya (JP); **Atsuhiro Takagi**, Kariya (JP)

(73) Assignee: **Brother Kogyo Kabushiki Kaisha**, Nagoya (JP)

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(51) **Int. Cl.**[7] **B41J 2/045**
(52) **U.S. Cl.** **347/72**
(58) **Field of Search** 347/68, 69, 70, 347/71, 72

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Primary Examiner—Anh T. N. Vo
(74) *Attorney, Agent, or Firm*—Oliff & Berridge, PLC

(57) **ABSTRACT**

Odd-numbered piezoelectric sheets **22**, **21***b*, **21***d*, and **21***f* are formed with a plurality of individual electrodes **24**. Even-numbered piezoelectric sheets **21***a*, **21***c*, **21***e*, and **21***g* are formed with a common electrode **25**. These odd-numbered and even-numbered piezoelectric sheets are alternatively arranged one on the other to form a laminated body. A top sheet **23** is mounted on the laminated body. Surface electrodes **30**, **31** are formed on the top sheet **23**. Through holes **32**, **33** are opened to the piezoelectric sheets **21***a* through **21***g* for providing electrical connection of the individual electrodes **24** and the common electrodes **25**, but not to the piezoelectric sheet **22** that is laminated on a cavity plate **10**.

12 Claims, 12 Drawing Sheets

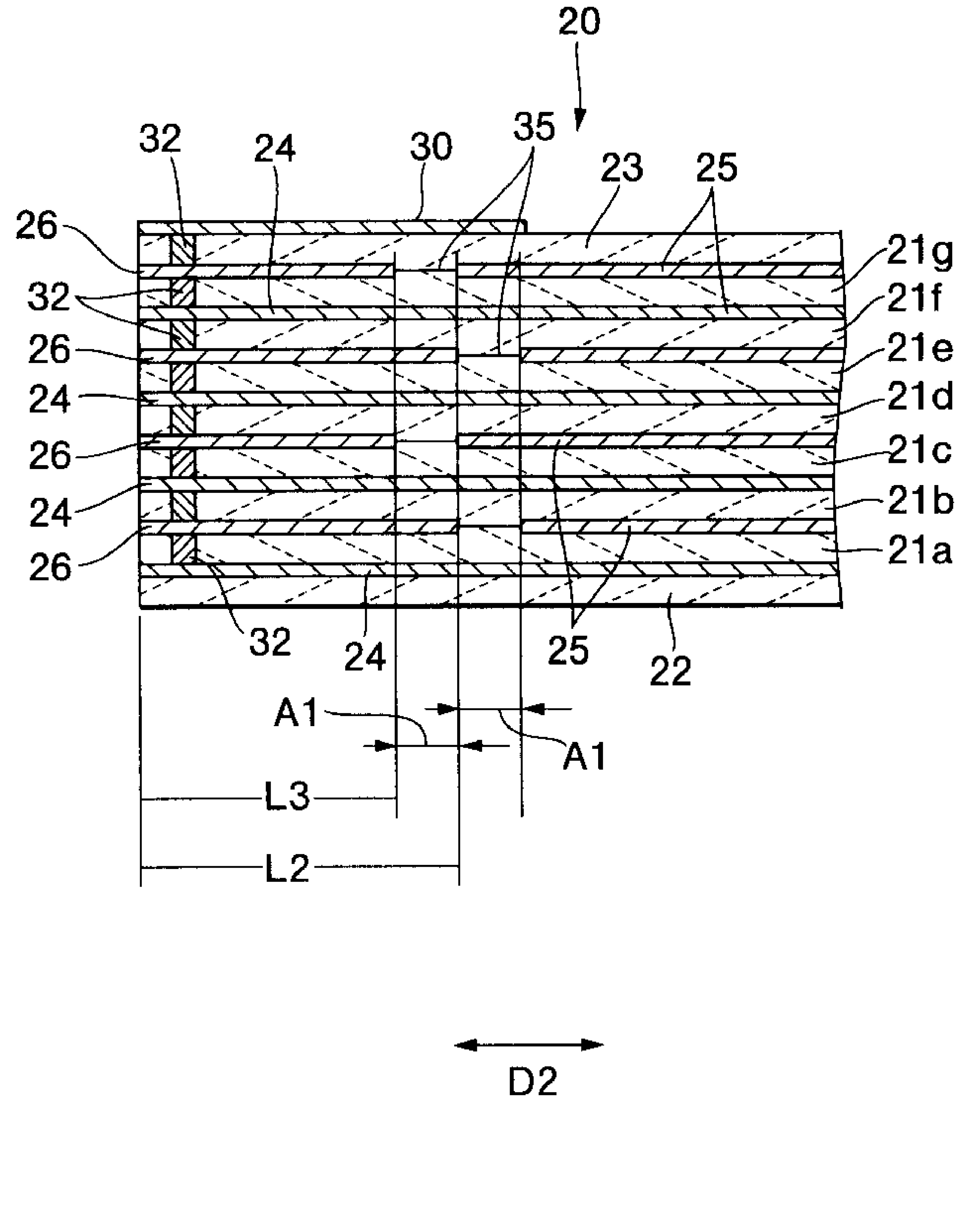


FIG.1

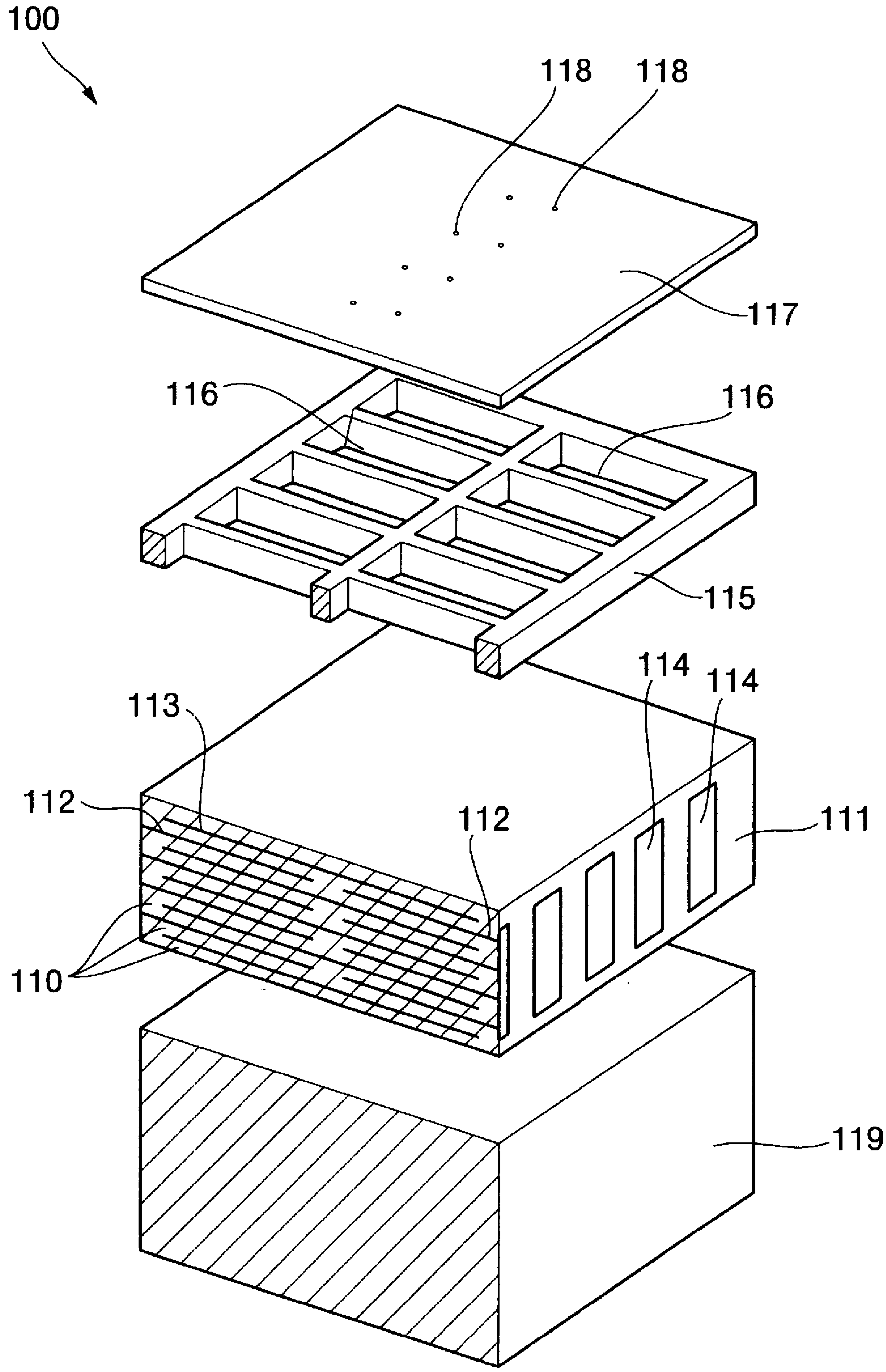


FIG.2

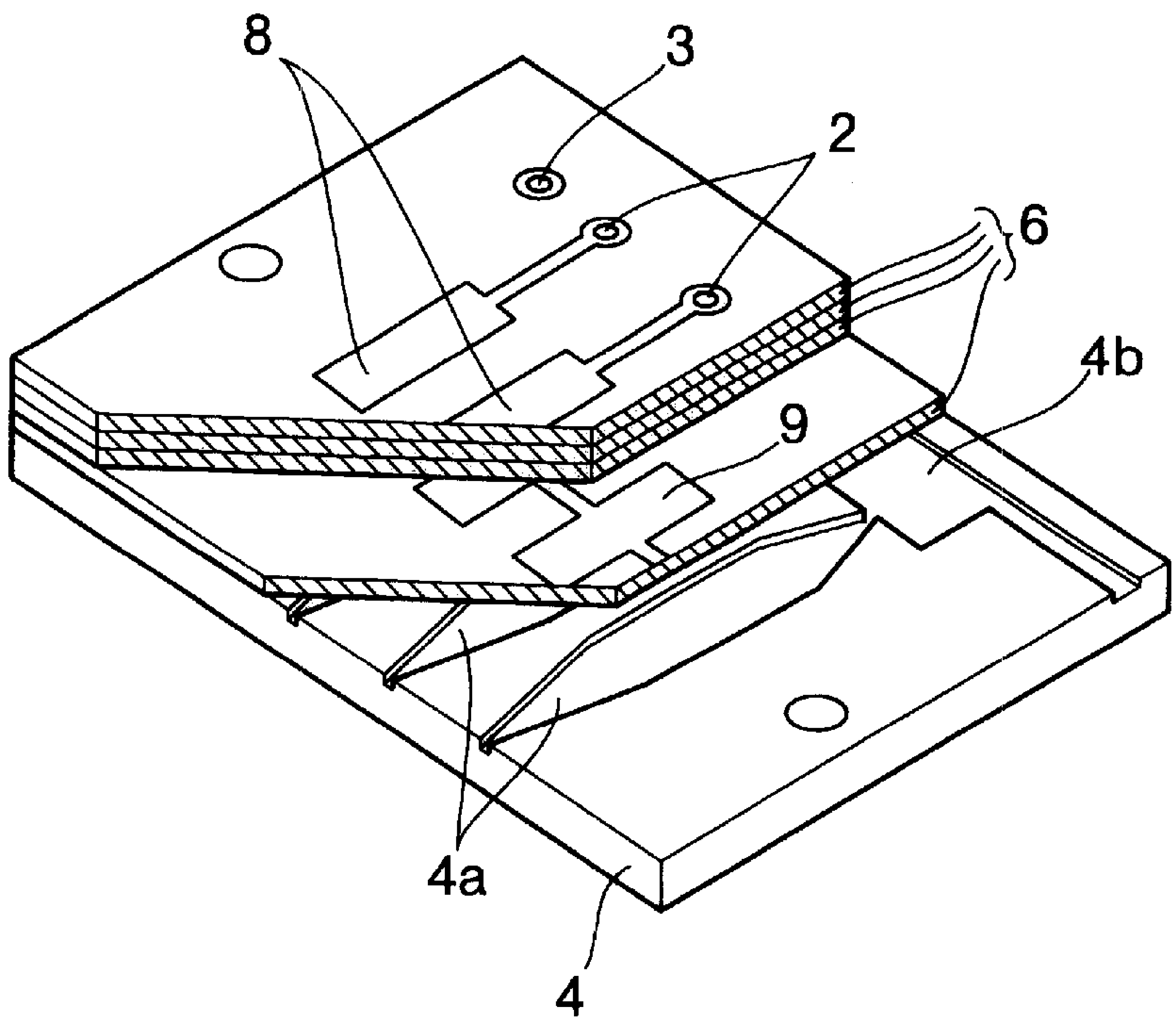


FIG.3

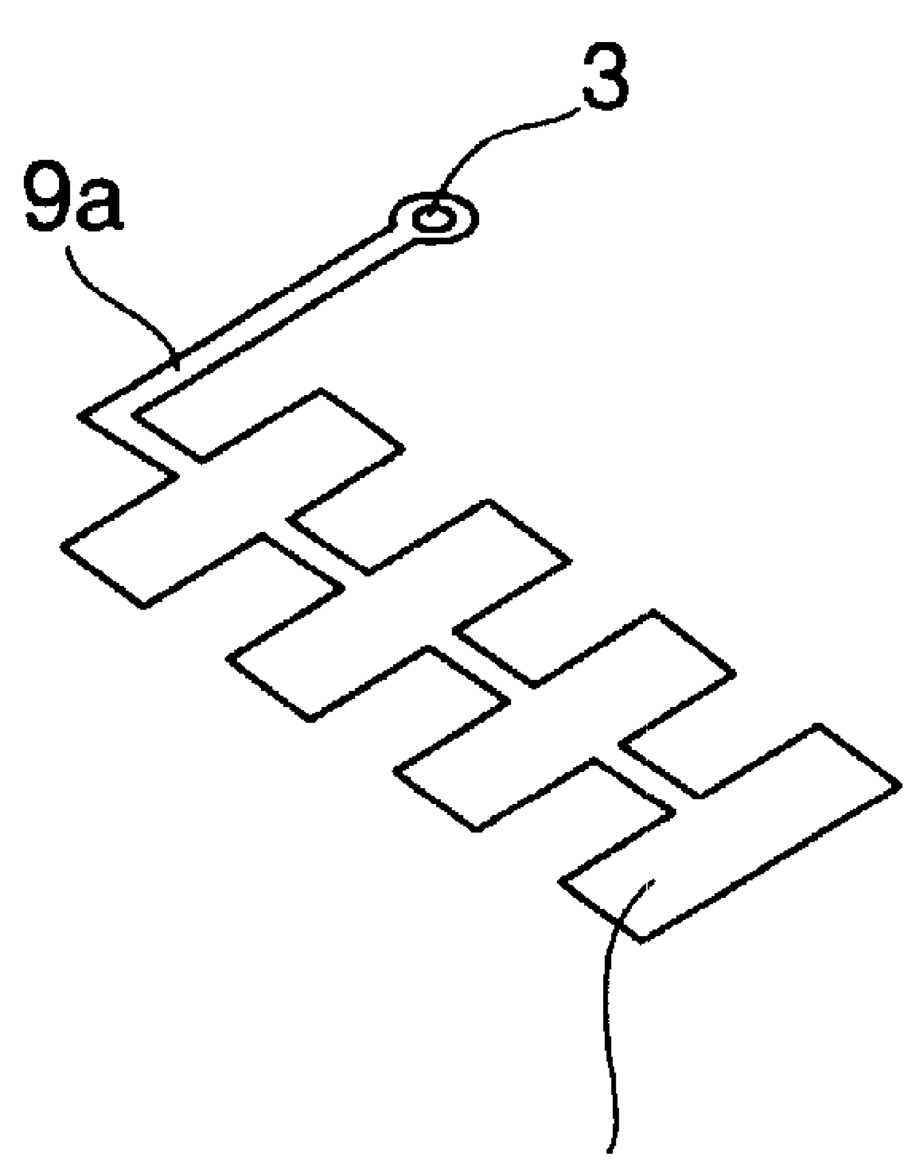


FIG.4

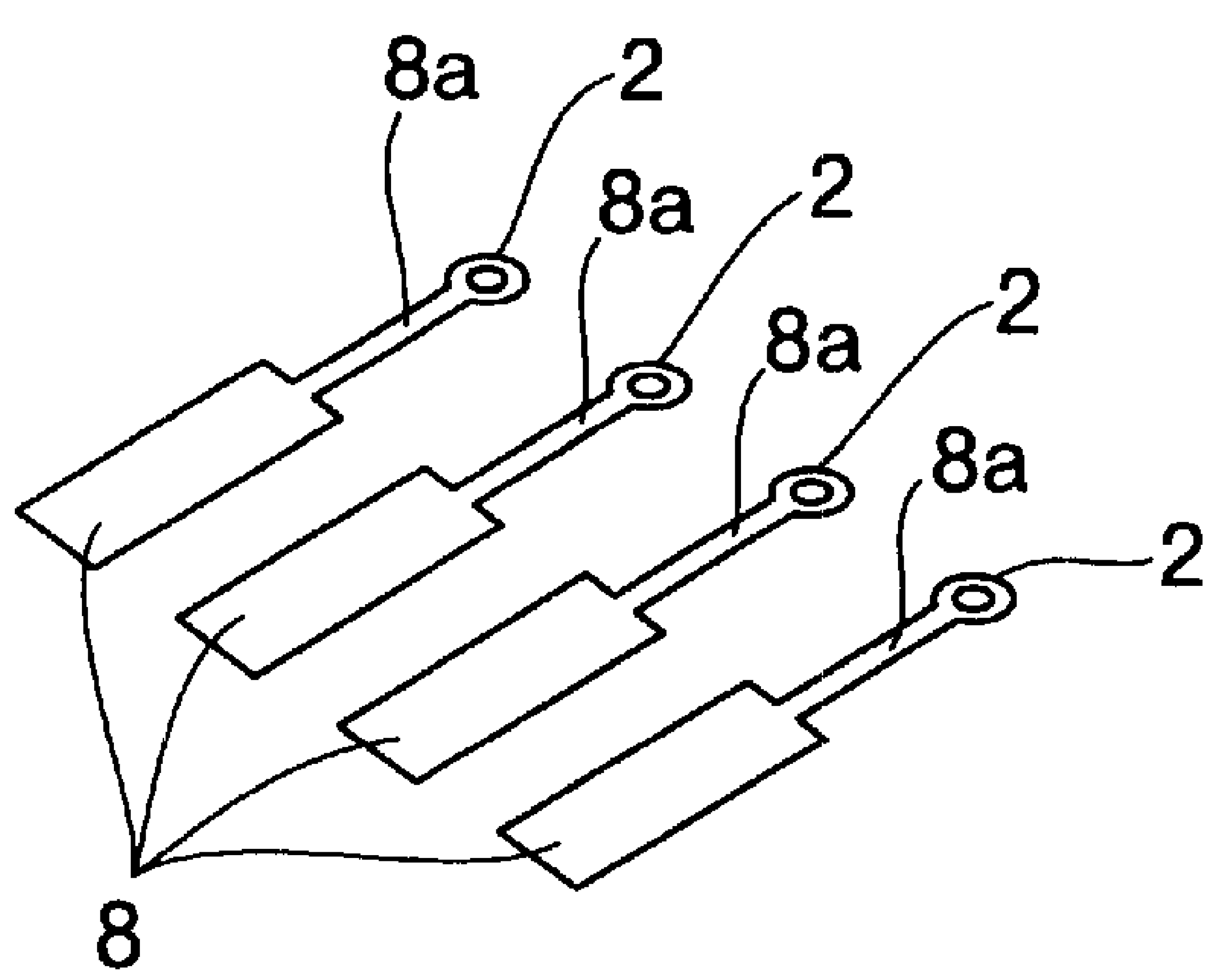


FIG.5

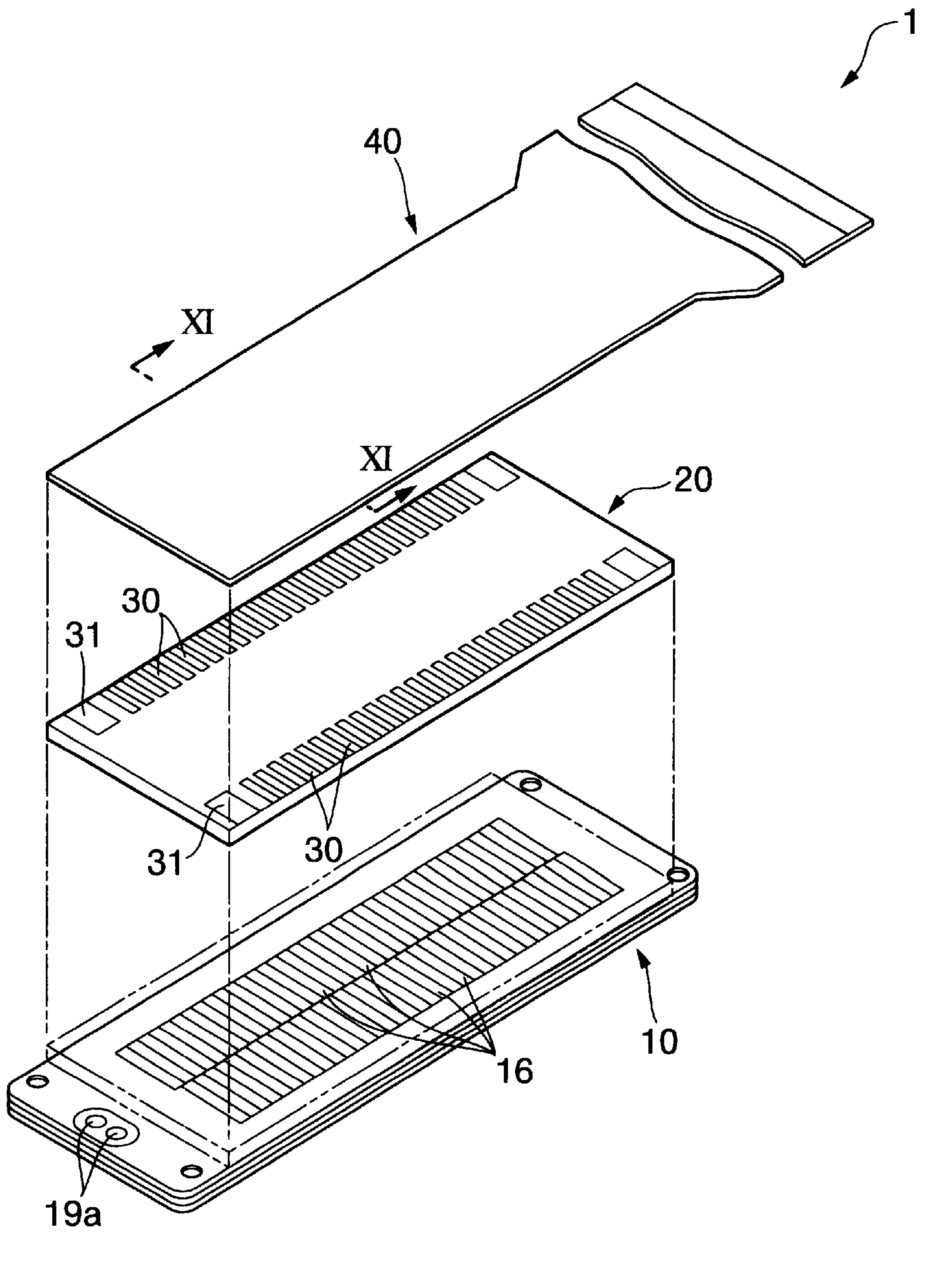


FIG.6

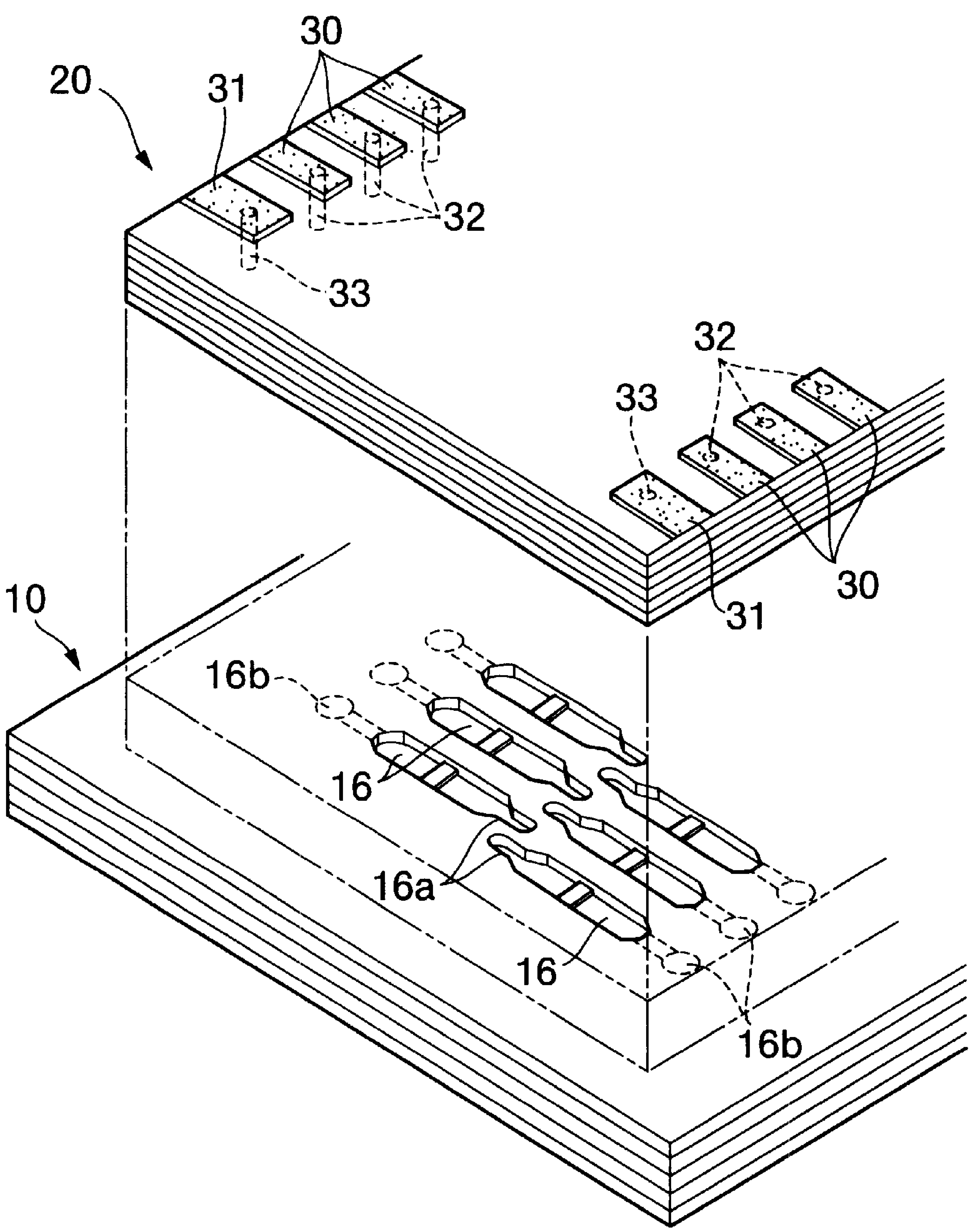
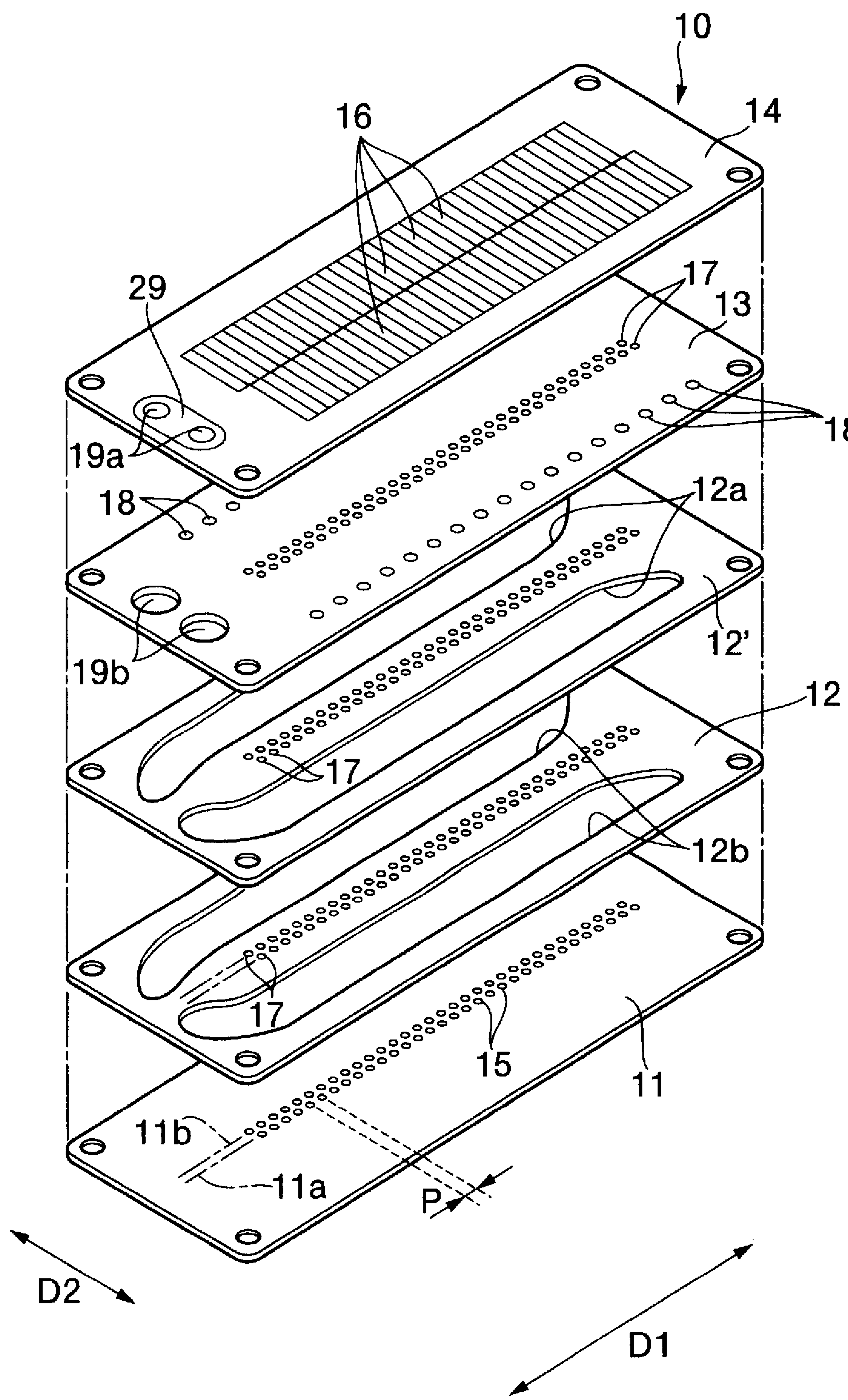


FIG.7



10
14
16
29
17
13
18
19a
18
12a
12'
19b
12
17
12b
17
15
11
11b
11a
P
D2
D1

FIG.8

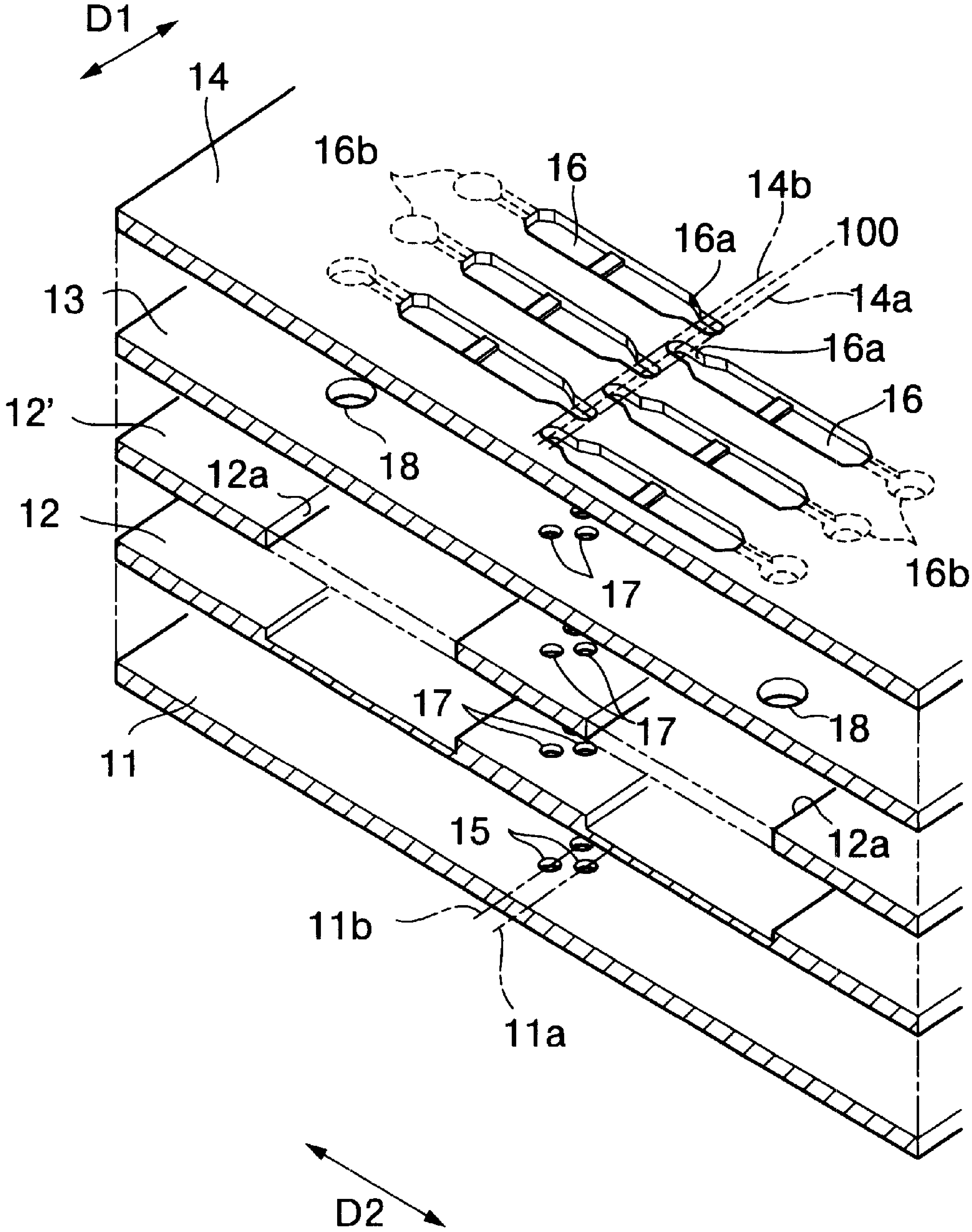
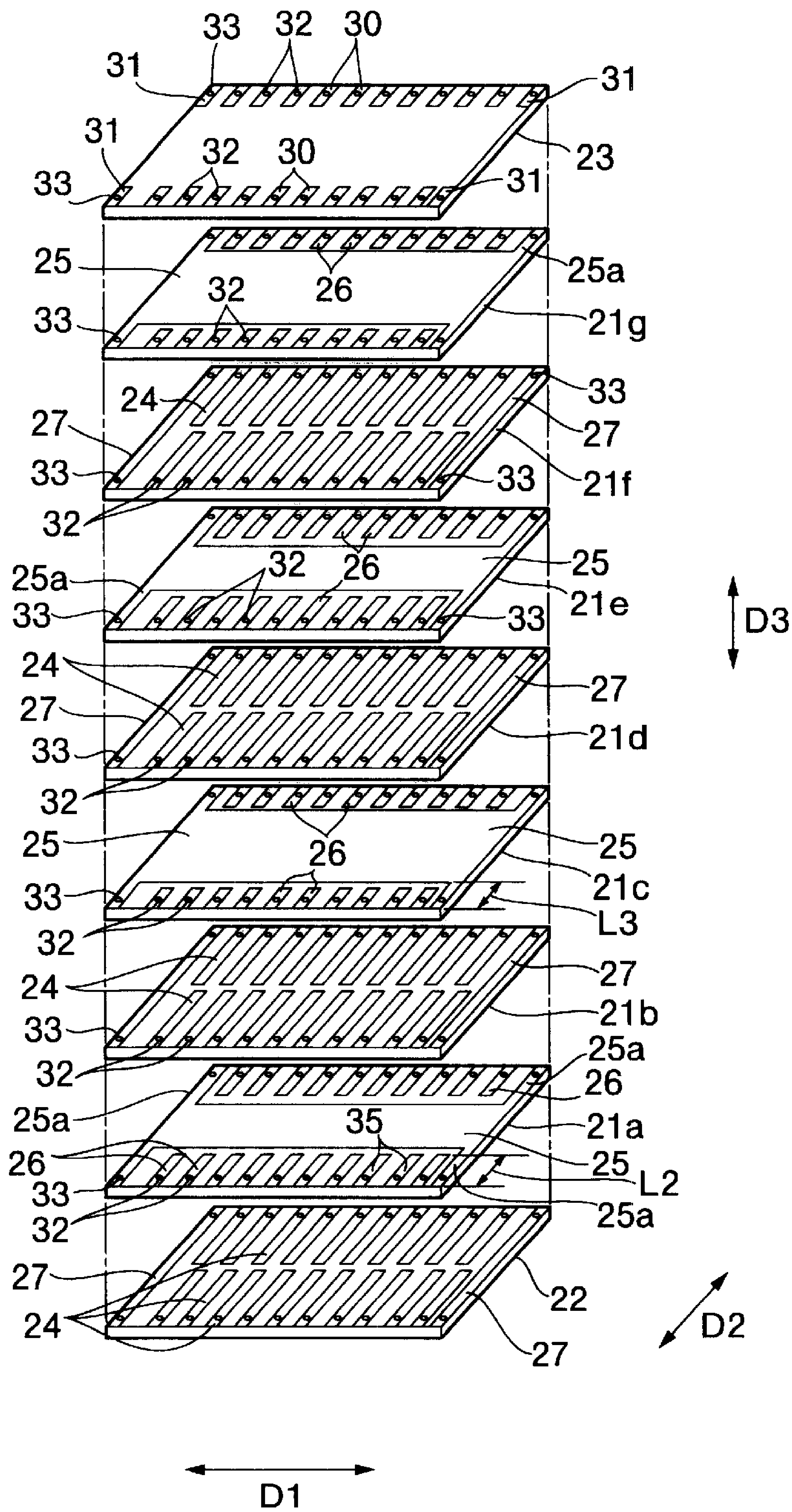

D1
14
16b
16
14b
16a
100
14a
13
16a
16
12'
18
12a
12
17
16b
18
17
17
11
12a
15
11b
11a
D2

FIG.9


33
32
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31
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23
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33
31
25
25a
32
26
33
21g
24
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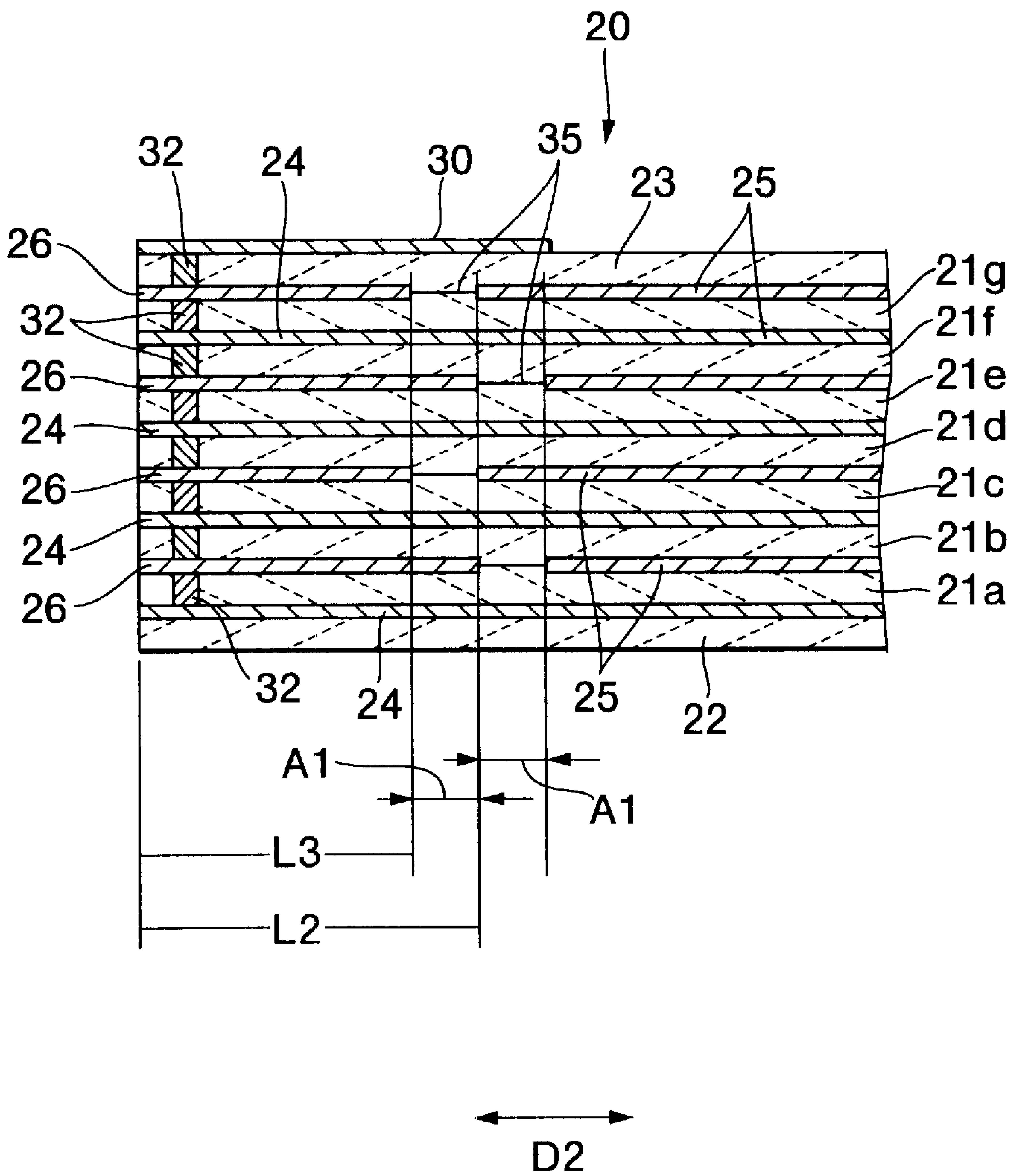
27
27
33
33
21f
32
25a
32
26
25
33
21e
33
D3
24
27
27
21d
33
32
25
25
26
21c
33
L3
32
24
27
21b
33
32
25a
26
25a
21a
35
26
25
33
L2
32
25a
27
22
24
D2
27
D1

FIG.10


20
32
24
30
35
23
25
26
21g
32
21f
26
21e
24
21d
26
21c
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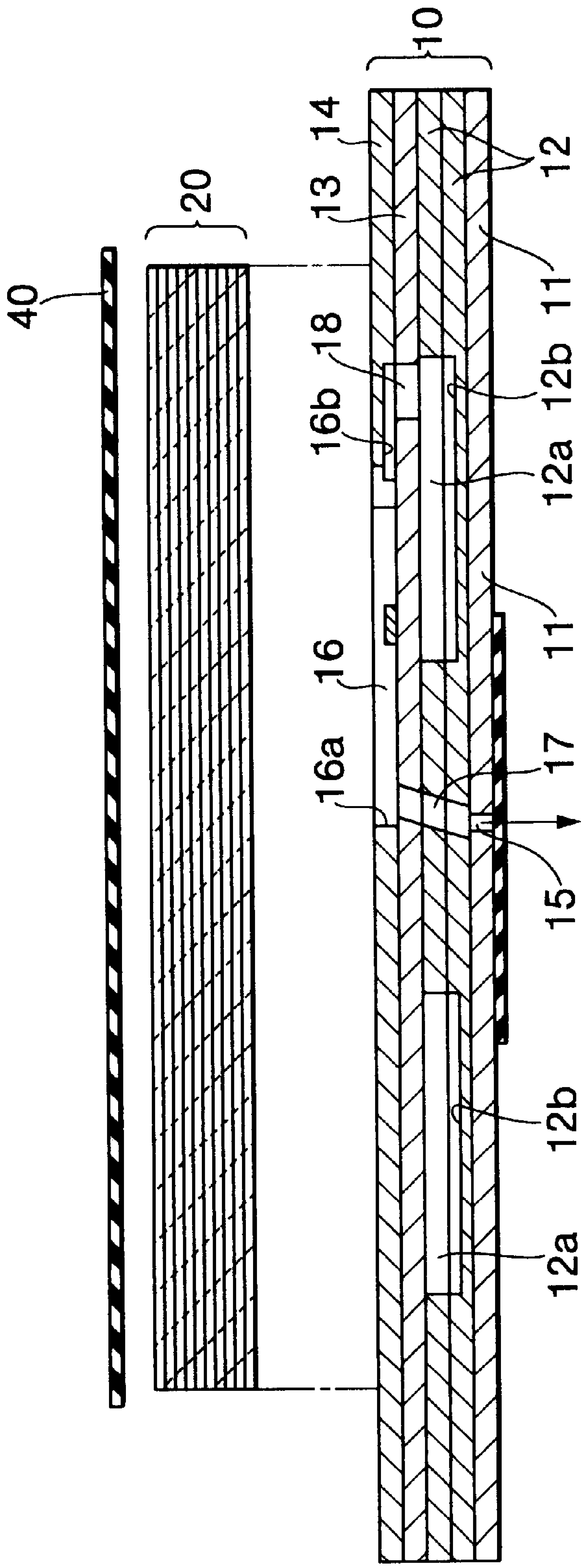
26
21a
32
24
25
22
A1
A1
L3
L2
D2

FIG.11



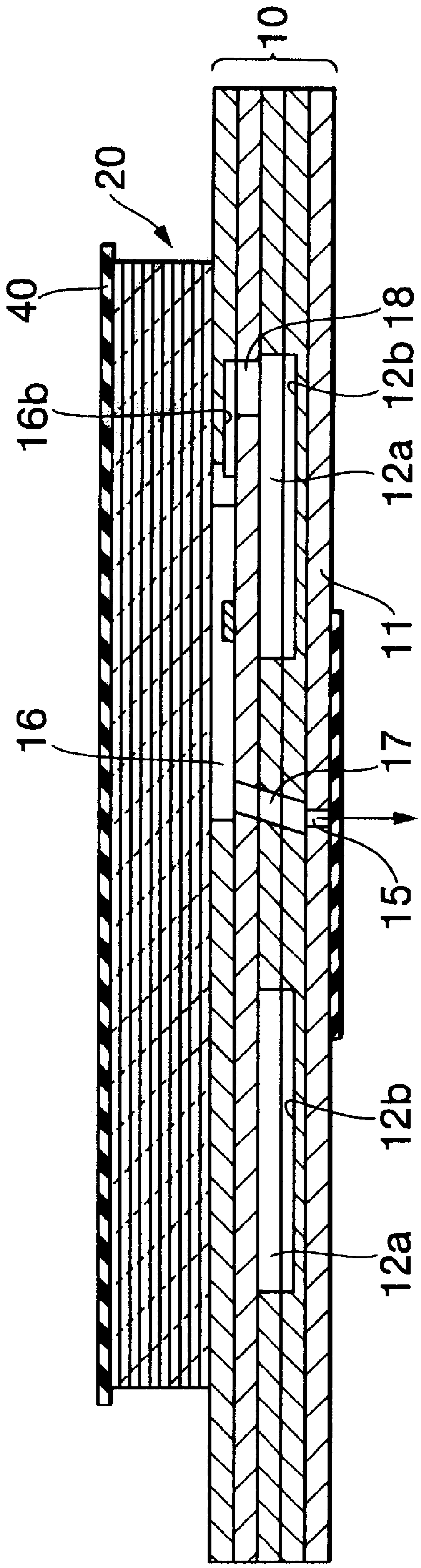
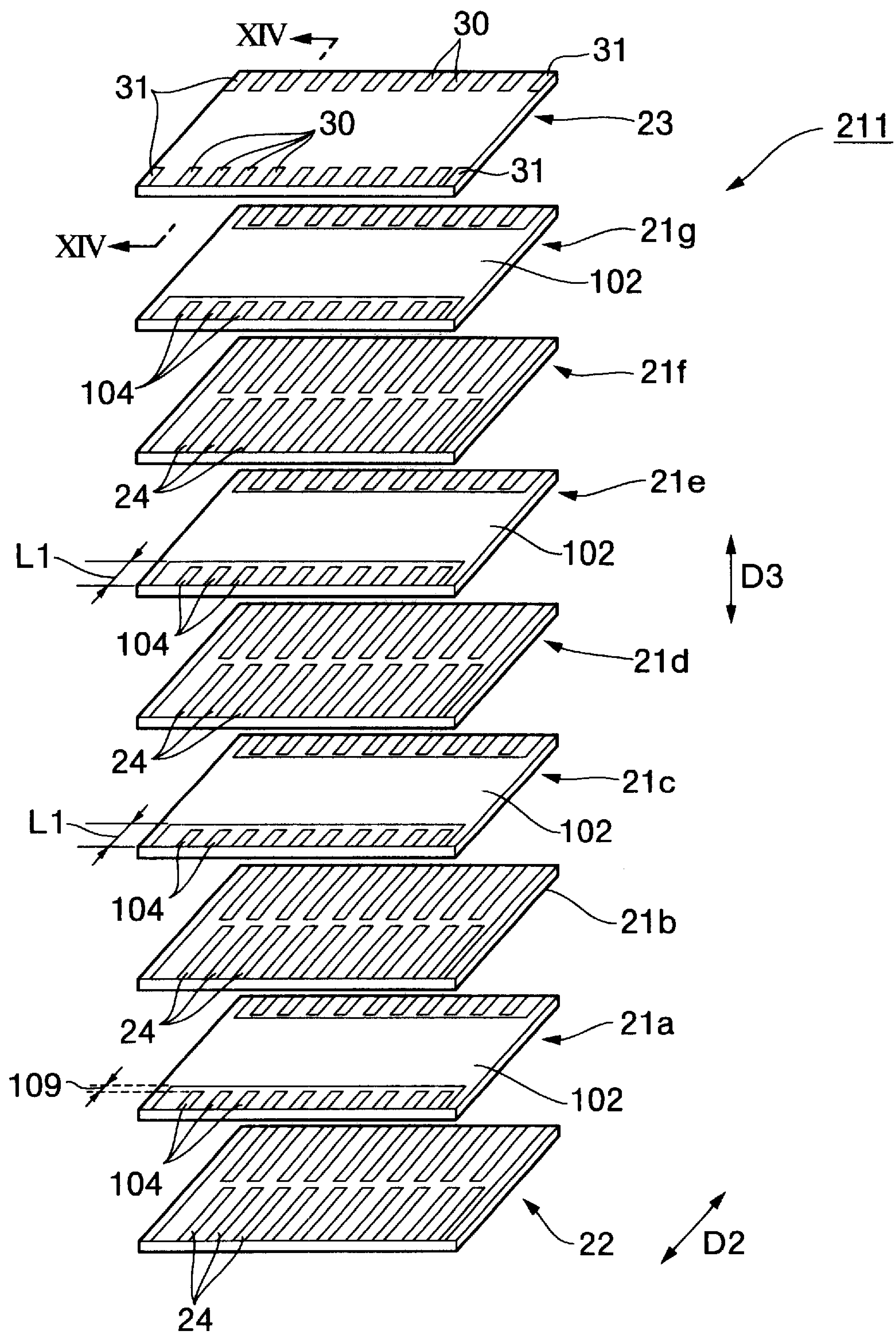


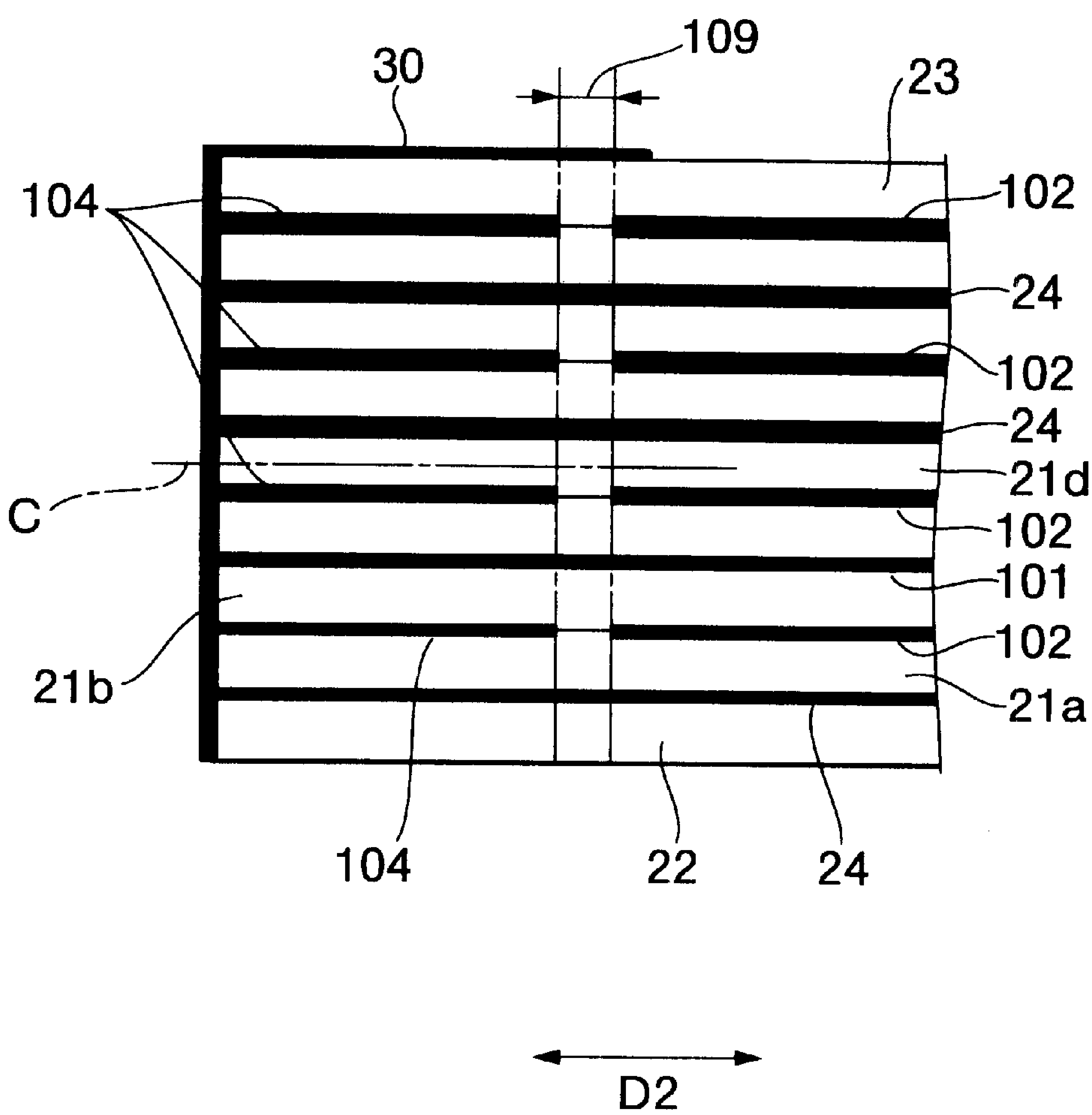
FIG.12

FIG.13



XIV
30
31
31
30
23
211
31
XIV
21g
102
104
21f
24
21e
L1
102
D3
104
21d
24
21c
L1
102
104
21b
24
21a
109
102
104
22
D2
24

FIG.14



PIEZOELECTRIC ACTUATOR OF INK JET PRINTER HEAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a piezoelectric actuator in the form of a plate used in a piezoelectric ink jet printer head, and more specifically to configuration of common electrodes and individual electrodes of such a piezoelectric actuator.

2. Description of Related Art

FIG. **1** shows a conventional piezoelectric ink jet printer head **100** disclosed in U.S. Pat. No. 5,402,159. As shown in FIG. **1**, the conventional head **100** includes a nozzle plate **117**, a cavity plate **115**, a piezoelectric actuator **111** in the form of a plate, and a back plate **119**. The nozzle plate **117** is formed with a plurality of nozzles **118**. The cavity plate **115** is formed with a plurality of ink cavities **116**, each corresponding to one of the plurality of nozzles **118**.

The piezoelectric actuator **111** includes a plurality of piezoelectric ceramic layers **110** called green sheets. Individual electrodes **112** are formed on each of a half of the piezoelectric ceramic layers **110**, and a common electrode **113** is formed on each of another half of the piezoelectric ceramic layers **110**. These two types of layers are alternatively arranged one on the other to have a laminated structure. Each of the individual electrodes **112** corresponds to one of the ink cavities **116**. The common electrodes **113** are common to all the ink cavities **116**.

The piezoelectric actuator **111** also includes outer electrodes **114** formed on its side surface by vacuum metallizing, metal spattering, conductive paste coating, or the like. Each outer electrode **114** electrically connects one of the sets of the individual electrodes **112** to the outside.

However, in this configuration, when the end portion of each individual electrode **112** may not reach the side surface of the piezoelectric actuator **111**, the electrical connection between the individual electrode **112** and the outer electrode **114** would be insufficient. Also, during the conductive paste coating and the like for forming the outer electrode **114**, the orientation of the piezoelectric actuator **111** is changed such that its side surface faces upward. This complicates the production process.

Moreover, there is a danger that the electrical connection of the electrodes **112** and **114** is damaged by accidentally contacting a handler or a tool during the production or assembly of the piezoelectric actuator **111**.

In order to overcome these problems, as shown in FIGS. **2** through **4**, Japanese Patent Publication No. HEI-7-96301 has proposed to form a lead-out electrode **8**_a_, **9**_a_ to each of the individual and common electrodes **8**, **9**. A plurality of first through-holes **2** are formed to penetrate through piezoelectric ceramic sheets **6** and the lead-out electrodes **8**_a_ of the corresponding individual electrodes **8**. Also, a second through hole **3** is formed to penetrate through piezoelectric ceramic sheets **6** and the lead-out electrodes **9**_a_ of the common electrodes **9**. Then, each of the first and second through holes **2**, **3** are filled with conductive paste, so that the individual electrodes **8** and the common electrodes **9** are electrically connected to an external electrode through the through holes **2** and **3**.

In this case, the through holes **2**, **3** are formed to all the piezoelectric ceramic sheets **6**, but not to a cavity plate **4**, which is formed with ink cavities **4**_a_ and an ink channel **4**_b_.

However, because the cavity plate **4** is formed from a piezoelectric ceramic sheet also, when the through holes **2**, **3** are formed connected to the ink cavities **4**_a_ or the ink channel **4**_b_, short circuits will result. Therefore, in order to avoid the short circuit, positions of the through holes **2**, **3** need to be carefully selected, and so the configuration of a piezoelectric actuator is strictly restricted.

SUMMARY OF THE INVENTION

Accordingly, it is an objective of the present invention to overcome the above problems, and also to provide a piezoelectric actuator with a configuration enabling simplifying a production process while avoiding short circuits and warping.

In order to achieve the above and other objectives, there is provided an ink jet print head including a cavity plate and a piezoelectric actuator. The cavity plate is formed with a plurality of nozzles and a plurality of pressure chambers each corresponding to one of the plurality of nozzles. The piezoelectric actuator includes a plurality of first piezoelectric sheets extending in a first direction, a plurality of second piezoelectric sheets extending in the first direction, a plurality of individual electrodes each corresponding to one of the plurality of pressure chambers and formed on the surface of the first piezoelectric sheets, and a plurality of common electrodes common to the plurality of pressure chambers and formed on the surface of the second piezoelectric sheets. The first piezoelectric sheets and the second piezoelectric sheets are arranged one on the other in alternation in a second direction perpendicular to the first direction so as to form a laminated structure. One of the first and second piezoelectric sheets at an end of the laminated structure lies on the cavity plate. The piezoelectric actuator is formed with first through holes formed in each of the first and second piezoelectric sheets in the second direction, except the one of the first and second piezoelectric sheets lying on the cavity plate. Each of the plurality of individual electrodes is formed at a position corresponding to the first through holes on the first piezoelectric sheets. The first through holes is filled with conductive material, thereby electrically connecting corresponding ones of the plurality of individual electrodes.

There is also provided a piezoelectric actuator used in a recording head including a cavity plate formed with a plurality of nozzles aligned in a first direction, and a plurality of channels each corresponding to one of the plurality of nozzles. The piezoelectric actuator includes a plurality of first piezoelectric sheets having a surface, a plurality of second piezoelectric sheets having a surface, and a plurality of first electrode patterns. The plurality of first piezoelectric sheets and the plurality of second piezoelectric sheets are arranged one on the other in a thickness direction perpendicular to the first direction. Each of the first electrode patterns is formed on the surface of one of the plurality of first piezoelectric sheets, and formed with a gap having a width in a second direction perpendicular to both the first direction and the thickness direction. The gaps of ones of the first electrode patterns are positioned shifted in the second direction from the gaps of another ones of the first electrode patterns.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** is an exploded perspective view of a conventional piezoelectric ink jet printer head;

FIG. **2** is a perspective cutout view of a conventional piezoelectric actuator;

FIG. **3** is a plan view of a common electrode of the piezoelectric actuator of FIG. **2**;

FIG. **4** is a plan view of individual electrodes of FIG. **2**;

FIG. **5** is an exploded perspective view of a piezoelectric ink jet print head according to an embodiment of the present invention;

FIG. **6** is an exploded perspective partial view of FIG. **5**;

FIG. **7** is an exploded perspective view of a cavity plate of the print head of FIG. **5**;

FIG. **8** is an exploded perspective partial view of the cavity plate;

FIG. **9** is an exploded perspective view of a piezoelectric actuator of the print head of FIG. **5**;

FIG. **10** is a cross-sectional view of the piezoelectric actuator;

FIG. **11** is an explanatory cross-sectional view taken along a line XI—XI of FIG. **5**;

FIG. **12** is an explanatory cross-sectional view of the print head;

FIG. **13** is an exploded perspective view of a conceivable piezoelectric actuator; and

FIG. **14** is a cross-sectional view taken along a line XIV—XIV of FIG. **13**.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Next, a piezoelectric ink jet print head **1** according to an embodiment of the present invention will be described. As shown in FIGS. **5**, **11**, and **12**, the piezoelectric ink jet print head **1** includes a cavity plate **10** made from a metal, a plate-shaped piezoelectric actuator **20**, and a flexible cable **40** to be connected with an external device. The piezoelectric actuator **20** is laminated on the cavity plate **10**. The flexible cable **40** is adhered onto the upper surface of the cavity plate **10** by an adhesive.

As shown in FIGS. **7** and **8**, the cavity plate **10** includes five thin metal plates laminated together. The thin plates include a nozzle plate **11**, two manifold plates **12**, **12**', a spacer plate **13**, and a base plate **14**. The nozzle plate **11** is formed with small-diameter ink ejection nozzles **15**. The nozzles **15** are formed in two rows that extend in a lengthwise direction D1 of the nozzle plate **11** in a staggered pattern. The nozzles **15** are opened separated from each other by small pitch P along two imaginary reference lines **11***a*, **11***b*.

The lower manifold plate **12**, which confronts the nozzle plate **11**, is formed with a pair of ink channels **12***b*, and the manifold plate **12**' is formed with a pair of ink channels **12***a*. The ink channels **12***a*, **12***b* extend along the sides of the rows of nozzles **15** in the lengthwise direction D1. As shown in FIG. **8**, the ink channels **12***a* in the upper manifold plate **12**' are formed as through holes through the manifold plate **12**'. On the other hand, the ink channels **12***b* in the lower manifold plate **12** are formed as indentations with the open side facing upward. Because the spacer plate **13** is laminated onto the upper manifold plate **12**', the ink channels **12***a*, **12***b* are in a sealed condition.

The base plate **14** is formed with narrow-width pressure chambers **16** that extend in a widthwise direction D2, which is perpendicular to an imaginary central line **100** that follows the lengthwise direction D1. One half of the pressure chambers **16** are disposed substantially to the left of the imaginary central line **100** and the other half is disposed substantially to the right of the imaginary central line **100** in a staggered arrangement. Assuming that imaginary reference lines **14***a*, **14***b* extend parallel with the imaginary central line **100** and are disposed equidistance from the imaginary central line **100** on left and right sides thereof, respectively, tips **16***a* of pressure chambers **16** to the left of the imaginary central line **100** are aligned on the right-hand reference line **14***a* and the tips **16***a* of pressure chambers **16** to the right of the imaginary central line C are aligned on the left-hand reference line **14***b*.

Small through holes **17** are opened in the same staggered arrangement in the spacer plate **13** and the manifold plates **12**, **12**'. The through holes **17** bring the tips **16***a* of the pressure chambers **16** into fluid communication with the corresponding nozzles **15**. Rows of through holes **18** are opened in both left and right sides of the spacer plate **13**. The through holes **18** bring the other ends **16***b* of the pressure chambers **16** into fluid communication with the ink channels **12***a*, **12***b* of the manifold plates **12**, **12**'. It should be noted that as shown in FIG. **8**, the other ends **16***b* are formed with an indented shape opened at the downward-facing-side of the base plate **14**. Also, as shown in FIG. **7**, supply holes **19***a* are opened in one end of the base plate **14**, and supply holes **19***b* are opened in one end of the spacer plate **13**. A filter **29** is stretched across the supply holes **19***a* from above for removing debris from an ink supplied from an ink tank (not shown), which is disposed above the base plate **14**.

With this configuration, the ink supplied from the ink tank flows through the supply holes **19***a*, **19***b*, the ink channels **12***a*, **12***b*, the through holes **18**, the pressure chambers **16**, and the through holes **17** in this order, and then the ink reaches the nozzles **15** corresponding to the pressure chambers **16**.

As shown in FIGS. **9** and **10**, the piezoelectric actuator **20** includes nine laminated piezoelectric sheets **22**, **21***a*, **21***b*, **21***c*, **21***d*, **21***e*, **21***f*, **21***g*, and **23**. Counting up from the lowermost piezoelectric sheet **22**, odd-numbered piezoelectric sheets **22**, **21***b*, **21***d*, and **21***f* are formed at their upper surface, which is the broadest surface, with a plurality of thin individual electrodes **24** for each of the pressure chambers **16** in the cavity plate **10**. The individual electrodes **24** are aligned in rows extending in lengthwise direction D1. Each individual electrode **24** extends in the widthwise direction D2 to the corresponding lengthwise edge of the corresponding piezoelectric sheet.

The even-numbered piezoelectric sheets **21***a*, **21***c*, **21***e*, **21***g* are formed at their upper surface with common electrodes **25**, which are shared commonly by all of the pressure chambers **16**.

As can be understood by comparing FIGS. **8** and **9**, the individual electrodes **24** are formed with a width sufficient to cover the wide-width portion of the pressure chambers **16**,

As described above, the pressure chambers **16** are arranged in two rows along the lengthwise direction D1, substantially through the widthwise center of the base plate **14**. Therefore, in order to integrally cover the two rows of pressure chambers **16**, **16**, each common electrode **25** is formed in a substantially rectangular shape, as viewed in plan, extending in the lengthwise direction D1 through the substantial center in the widthwise direction D2. Also, leads **25***a*, **25***a* are formed integrally with the common electrodes **25** substantially across the entire widthwise ends of the even-numbered piezoelectric sheets **21***a*, **21***c*, **21***e*, **21***g*.

Individual dummy electrodes **26** are formed along lengthwise ends of the even-numbered piezoelectric sheets **21***a*, **21***c*, **21***e*, **21***g* at positions where the common electrodes **25** are not formed. The individual dummy electrodes **26** are formed at positions that correspond in a vertical sense to the individual electrodes **24** and have the same width in the lengthwise direction D1 as the individual electrodes **24**.

As shown in FIGS. **9** and **10**, the inward-facing tip of each individual dummy electrode **26** is separated from the common electrode **25** in the widthwise direction D2 by a space **35** of suitable width A1. Also, the individual dummy electrodes **26** are formed to different lengths L2 and L3, wherein L3<L2, in alternation. With this configuration, the position of the space **35** between the inward facing end of each individual dummy electrode **26** and the side edge of the common electrodes **25** is shifted in the widthwise direction D2 for every other piezoelectric sheet in the laminated stack.

More specifically, as shown in FIG. **10**, the dummy electrodes **26** on the piezoelectric sheets **21***a* and **21***e* are formed to the length L2. The individual dummy electrodes **26** on the piezoelectric sheets **21***c* and **21***g* are formed to the length L3. The length L2 is longer than the length L3 by a distance A1.

With this configuration, overall width of the spaces **35** in the widthwise direction D2 is as large as twice the distance A1 (2×A1). Also, the density of the electrodes **24**, **26** in a thickness, direction D3 is not clustered with respect to the second direction D2.

It should be noted that it is conceivable to form the piezoelectric actuator in a configuration as shown in FIGS. **13** and **14**, where all dummy electrodes **104** are formed to the same length L1 in the widthwise direction D2 and the inward-facing tip of each dummy electrode **104** is separated from a corresponding common electrode **102** in the widthwise direction D2 by a space **109**. However, this configuration has a following problem.

That is, usually electrodes are formed to piezoelectric sheets by conductive paste, and then the piezoelectric sheets are stacked one on the other, pressed, and sintered. At this time, each of the piezoelectric sheets shrinks in its thickness direction. However, the amount of the shrinkage is not uniform. Portion of the piezoelectric sheets formed with the electrodes shrinks more than that formed with no electrodes.

A center line C shown in FIG. **14** indicates a center of the piezoelectric actuator in the thickness direction D3. Within the space **109**, the distributions of the electrodes are uneven between the upper side and the lower side of the center line C. Specifically, as will be understood from FIG. **14**, the electrodes at the upper side clusters toward the center line C, and the electrodes at the lower side clusters away from the center line C. Accordingly, shrinkage of the piezoelectric electrodes at the lower side of the center line C during the manufacturing process makes the overall actuator sharply warp into a reversed V-shape with the portion of the space **109** to the top.

When, such a warp is large or sharp, a cavity plate will not be properly adhered to the actuator, and there will be an undesirable space formed between the cavity plate and the actuator, resulting in ink leak.

However, according to the configuration of the present embodiment, when considering the piezoelectric actuator **20** overall, the spaces **35** will be less clustered with respect to the widthwise direction D2, and the electrodes are less dense in the thickness direction D3 at the locations of the space **109**. Therefore, the piezoelectric actuator **20** will warp to a lesser extent in the thickness direction D3 when sintered in subsequent processes. Furthermore, because the sintered piezoelectric actuator **20** will have a smooth arched shape, the piezoelectric actuator **20** and the cavity plate **10** will be in intimate contact with no gaps therebetween when the piezoelectric actuator **20** is adhered and fixed to the cavity plate **10**. The resulting product will not have any leaks. Also, less adhesive pressure is required to press the piezoelectric actuator **20** and the cavity plate **10** flat together.

Common dummy electrodes **27** are formed on the upper surfaces of the odd-numbered piezoelectric sheets **22**, **21***b*, **21***d*, and **21***f* along the widthwise ends at positions that correspond vertically to the leads **25***a*, **25***a*.

Upper-surface electrodes **30**, **31** are formed along the lengthwise edge on the upper surface of the top sheet **23**. The upper-surface electrodes **30** are at positions corresponding to the individual electrodes **24**. The upper-surface electrodes **31** are at the four corners of the top sheet **23** for the common electrodes **25**.

Further, through holes **32** and **33** are opened in the top sheet **23** and all of the piezoelectric sheets **21***a* to **21***g*, but not in the lower-most piezoelectric sheet **22**. The through holes **32** are formed at positions corresponding to the surface electrodes **30**, the individual electrodes **24**, and the individual dummy electrodes **26**. The through holes **33** are formed at positions corresponding to the surface electrodes **31**, the leads **25***a*, of the common electrodes **25**, and the common dummy electrodes **27**. The through holes **32**, **33** are filled with conductive material to electrically connect together the upper-surface electrodes **30** and corresponding individual electrodes **24** of the different layers and, similarly, to electrically connect together the upper-surface electrodes **31** and the corresponding common electrodes **25** of different layers.

Next, a method for producing the piezoelectric actuator **20** will be described. First, a plurality of ceramic green sheets are prepared for the piezoelectric sheets **22**, **21***a*–**21***g*, and the top sheet **23**. Then, the through holes **32** are opened in each of the piezoelectric sheets **21***a*–h **21***g* at positions corresponding to the individual electrodes **24** and the common dummy electrodes **27**. In the same manner, the through holes **33** are opened in each of the piezoelectric sheets **21***a*–**21***g* at positions corresponding to the common electrodes **25** and the individual dummy electrodes **26**. Further, the through holes **32**, **33** are opened in the top sheet **23** at positions corresponding to the surface electrodes **30**, **31**.

Next, the individual electrodes **24** and the common dummy electrodes **27** are formed on the surface of each piezoelectric sheet **22**, **21***b*, **21***d*, **21***f* using screen printing with a conductive paste. The common electrode **25** and the individual dummy electrodes **26** are formed on the surface of each piezoelectric sheet **21***a*, **21***c*, **21***e*, **21***g* using screen printing with a conductive paste. Also, the surface electrodes **30**, **31** are formed on the surface of the top sheet **23** using screen printing with a conductive paste. At this time, because the through holes **32**, **33** are provided in the piezoelectric sheets **21***a*–**21***g* and the top sheet **23**, the conductive paste enters into the through holes **32**, **33** and brings the corresponding electrodes into electrical connection with each other at the upper surface and the lower surface of each of the sheets **21***a*–**21***g*, **23** when laminated one on the other.

After drying out, the piezoelectric sheets **22**, **21***a*–**21***g* and the top sheet **23** are stacked together in a manner shown in FIG. **9** and pressed into an integral laminated unit. Then, the resultant integral laminated unit is subjected to sintering.

As a result, the surface electrodes **30** formed on the top sheet **23** are electrically connected via the conductive paste in the through holes **32** to the individual electrodes **24** and the individual dummy electrodes **26** in correspondence in the vertical sense. Also, the surface electrodes **31** are electrically connected via the conductive paste in the through holes **33** to the common electrodes **25** and the common dummy electrodes **27** in correspondence in the vertical sense.

The piezoelectric actuator **20** produced in this manner is fixed in place to the cavity plate **10** in a manner shown in FIGS. **5** and **11** such that each individual electrode **24** is aligned with the corresponding pressure chamber **16**. Then, the flexible cable **40** is stacked and pressed on the upper surface of the piezoelectric actuator **20**. As a result, each type of wiring pattern (not shown) in the flexible cable **40** is electrically connected to the upper surface electrodes **30, 31**.

In this arrangement, when a voltage is applied between the common electrodes **25** and selected ones of the individual electrodes **24**, portions of the piezoelectric sheets **21, 22** corresponding to the individual electrodes **24** applied with the voltage deform in the thickness direction D3. As a result, the volume in the corresponding pressure chambers **16** drops, thereby ejecting an ink droplet from the corresponding nozzles **15**, so that printing is performed as shown in FIG. **12**.

As described above, according to the embodiment of the present invention, the electrical connection among the individual electrodes **24** and the surface electrodes **30** and among the common electrodes **25** and the surface electrodes **31** are achieved in the thickness direction D3 through the through holes **32, 33** formed in the piezoelectric sheets **21***a*–**21***g* and the top sheet **23**. Therefore, there is no danger that the electrical connection is damaged by accidental contact of a handler or a tool during production or assembly of the piezoelectric actuator **20**.

Moreover, because the through holes **32, 33** are not formed in the piezoelectric sheet **22** that directly contacts the cavity plate **10**, the individual electrodes **24** and the common electrodes **25** are in complete electric isolation from the cavity plate **10**, even if the cavity plate **10** is formed from a conductive material, such as 42% nickel-alloy steel. Also, because the through holes **32, 33** are not formed in the piezoelectric sheet **22**, the water-based ink in the pressure chambers **16** will not produce electrically short circuits even if the individual electrodes **24** or the common electrodes **25** are positioned with vertical overlap with any of the pressure chambers **16**.

As a result, the through holes **32, 33** can be formed anywhere in the piezoelectric actuator **20**, with no restriction to position, so that the piezoelectric actuator **20** can be designed with great freedom.

According to the embodiment of the present invention, the individual electrodes **24** and the common electrodes **25** are formed in alternation on the piezoelectric sheets **22, 21**. Also, the individual dummy electrodes **26** are formed vertically between the individual electrodes **24**, and the common dummy electrodes **27** are formed vertically between the common electrodes **25**. Also, the through holes **32** formed in the sheets **21, 23** and filled with the conductive paste reliably and electrically connect the individual dummy electrodes **26** to the vertically aligned corresponding individual electrodes **24**, and the through holes **33** formed in the sheets **21, 23** and filled with the conductive paste reliably and electrically connect the common electrodes **25** to the vertically aligned corresponding common dummy electrodes **27**.

Also, the dummy electrodes **26, 27** reduce the amount of deviation in thickness of the laminated piezoelectric sheets. If there are no individual dummy electrodes **26** or common dummy electrodes **27**, the laminated piezoelectric sheets will have uneven thickness.

It should be noted that the conductive material that is coated on the piezoelectric sheets to form the electrodes **24, 25, 30, 31** will enter into and fill the through holes **32, 33** when each piezoelectric sheet is 30 microns thick and when the each electrode **20, 25, 30, 31** are formed to about 5 microns thick. However, when the each piezoelectric sheet is fairly thick, the conductive material can be reliably drawn into the through holes **32, 33** by applying suction to the reverse side of the piezoelectric sheet from where the conductive material was coated.

While some exemplary embodiments of this invention have been described in detail, those skilled in the art will recognize that there are many possible modifications and variations which may be made in these exemplary embodiments while yet retaining many of the novel features and advantages of the invention.

For example, the surface electrodes **30, 31** can be formed with a metal layer thereon by energizing a narrow-width electrode pattern on the surface electrodes **30, 31** to perform electrolysis while the laminated body of the piezoelectric sheets are immersed in a plating solution. An example of the metal layer is a gold layer on top of a nickel layer serving as a based layer. Such a metal layer improves electrical connection between the wiring patterns in the flexible flat cable **40** with the corresponding surface electrode **30, 31**.

Needless to say, the order in which the layers of the individual electrodes **24** and of the common electrodes **25** are laminated can be changed as appropriate in order to bring the lower-most piezoelectric sheet with the common electrode **25** into confrontation with the base sheet **14** in the cavity sheet **10**. Also, instead of the through holes **32, 33**, side electrodes can be formed on the side surfaces of the laminated body of the piezoelectric actuator for the electrical connection among the electrodes **24, 25, 26, 27**. In this case, indented grooves can be formed to the side surfaces of the laminated body for exposing the electrodes **24, 25, 26, 27** and the side electrodes can be formed in the indented grooves.

Further, the present invention can be applied when the direction D1 is the direction along the short dimension of the piezoelectric actuator **20** and the direction D2 is the direction along the long dimension of the piezoelectric actuator **20**.

Also, there is no need to form all four through holes **33** as long as there is at least one through hole **33** opened to connect at least one surface electrode **31** with the corresponding leads **25***a* or the common electrodes **25**. In this case, at least one surface electrode **31** can be formed, rather than all four of the surface electrodes **31**.

Moreover, although in the above-described embodiment the piezoelectric sheet **22** is used as a bottom sheet of the piezoelectric actuator **20**, the sheet **22** can be formed of different insulation material as long as the sheet **22** can reliably transmits the deformation of the piezoelectric sheets **21***a* through **21***g*. Also, the top sheet **23** can be formed of insulation material other than the piezoelectric material. In this case, it is preferable that the top sheet **23** be able to suppress the upward warping of the piezoelectric actuator **20**.

Further, when the common electrodes **25** are connected to the ground, the through holes **33** can be electrically connected to the cavity plate **10**.

What is claimed is:

1. An ink jet print head comprising:

a cavity plate formed with a plurality of nozzles and a plurality of pressure chambers each corresponding to one of the plurality of nozzles; and a piezoelectric actuator including:

a plurality of first piezoelectric sheets extending in the first direction;

a plurality of second piezoelectric sheets extending in the first direction, wherein the first piezoelectric sheets and the second piezoelectric sheets are arranged one on the other in alternation in a second direction perpendicular to the first direction so as to form a laminated structure, one of the first and second piezoelectric sheets at an end of the laminated structure lying on the cavity plate, and first through holes are formed in each of the plurality of first and second piezoelectric sheets in the second direction, except the one of the first and second piezoelectric sheets lying on the cavity plate; and

the piezoelectric actuator is formed with a plurality of individual electrodes each corresponding to one of the plurality of pressure chambers and formed on the surface of the first piezoelectric sheets at positions corresponding to the first through holes, and a plurality of common electrodes common to the plurality of pressure chambers and formed on the surface of the second piezoelectric sheets,

the first through holes being filled with conductive material, thereby electrically connecting corresponding ones of the plurality of individual electrodes in the second direction.

2. The ink jet print head according to claim **1**, wherein at least one second through hole is formed in each of the plurality of first and second piezoelectric sheets in the second direction except the one of the first and second piezoelectric sheets lying on the cavity plate, the at least one second through hole being filled with conductive material, thereby electrically connecting the plurality of common electrodes.

3. The ink jet print head according to claim **2**, wherein the piezoelectric actuator further comprises:

a third sheet extending in the first direction and lying on another end of the laminated structure such that the third sheet and the cavity plate sandwich the laminated structure therebetween, the third sheet having third through holes and at least one fourth through hole that penetrate through the third sheet;

a plurality of first surface electrodes formed on the surface of the third sheet each corresponding to one of the pressure chambers; and

at least one second surface electrode formed on the surface of the third sheet, wherein the first surface electrodes are positioned over the third through holes and the at least one second surface electrode is positioned over the at least one fourth through hole, the third through holes being filled with the conductive material, thereby electrically connecting each of the first surface electrodes and the corresponding ones of the plurality of individual electrodes in the second direction, and the at least one fourth through hole being filled with the conductive material, thereby electrically connecting the at least one second surface electrode and the plurality of common electrodes.

4. The ink jet print head according to claim **2**, wherein the piezoelectric actuator further comprises:

a plurality of individual dummy electrodes formed on each of the plurality of second piezoelectric sheets each dummy electrode aligned in the second direction with one of the plurality of individual electrode on each of the plurality of first piezoelectric sheets; and

a common dummy electrode on each of the first piezoelectric sheets aligned in the second direction with the common electrode on each of the plurality of second piezoelectric sheets, wherein the first through holes further electrically connect corresponding ones of the individual dummy electrodes with the corresponding ones of the individual electrodes, and the at least one second through hole further electrically connects the common dummy electrodes.

5. A piezoelectric actuator used in a recording head including a cavity plate formed with a plurality of nozzles aligned in a first direction, and a plurality of channels each corresponding to one of the plurality of nozzles, the piezoelectric actuator comprising:

a plurality of first piezoelectric sheets having a surface;

a plurality of second piezoelectric sheets having a surface, wherein the plurality of first piezoelectric sheets and the plurality of second piezoelectric sheets are arranged one on the other in alternation in a thickness direction perpendicular to the first direction; and

a plurality of first electrode patterns each formed on the surface of one of the plurality of first piezoelectric sheets, and each formed with a gap having a width in a second direction perpendicular to both the first direction and the thickness direction, wherein gaps of ones of the first electrode patterns are positioned shifted in the second direction from the gaps of another ones of the first electrode patterns, and the gaps extend in the first direction.

6. The piezoelectric actuator according to claim **5**, further comprising a plurality of second electrode patterns each formed on the surface of one of the second piezoelectric sheets, wherein each of the second electrode patterns includes a plurality of individual electrodes each corresponding to one of the plurality of pressure chambers, and each of the first electrode pattern includes a plurality of individual dummy electrodes each corresponding to one of the plurality of pressure chambers.

7. The piezoelectric actuator according to claim **6**, wherein the surface of each of the first and second piezoelectric sheets has a side edge extending in the first direction, and the plurality of individual electrodes of each second electrode pattern are aligned along the side edge of the surface of the corresponding second piezoelectric sheet, and the plurality of individual dummy electrodes of each first electrode pattern are aligned along the side edge of the surface of the corresponding first piezoelectric sheet.

8. The piezoelectric actuator according to claim **6**, wherein each of the first electrode pattern further includes a common electrode formed at a center of corresponding one of the first piezoelectric sheets with respect to the second direction and extending in the first direction.

9. The piezoelectric actuator according to claim **8**, wherein the gap of the first electrode pattern is defined between the common electrode and the plurality of individual dummy electrodes.

10. The piezoelectric actuator according to claim **5**, wherein a through hole is opened to each of the first and second piezoelectric sheets in the thickness direction except one of the first and second piezoelectric sheets.

11. The piezoelectric actuator according to claim **10** wherein the through hole is filled with a conductive material, and the one of the first and the second piezoelectric sheets is brought into intimate contact with the cavity plate.

12. The piezoelectric actuator according to claim **5**, wherein the plurality of first electrode patterns includes a first set of patterns and a second sets of patterns, the first set of pattern including a plurality of first individual dummy electrodes having a first length in the second direction, the second sets of pattern includes a plurality of second individual dummy electrodes having a second length greater than the first length in the second direction.

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